

**TRANSMAP: AN INTEGRATED, REAL TIME
ENVIRONMENTAL MONITORING AND FORECASTING
SYSTEM FOR HIGHWAYS AND WATERWAYS IN RI**

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| 16. Abstract <p>This report summarizes the work accomplished during the second year of a three-year project to develop a state of the art, integrated environmental monitoring and modeling system to provide data and information to support the operation, management, and evaluation of various land and marine based transportation systems in RI. TRANSMAP features an open architecture, industry standard software tools and modules, an embedded geographic information system (GIS), standardized data handling protocols, an environmental data analysis and presentation system, and access for linkage to models and management tools. The second year project objectives were to (1) to complete access to the RI roadway weather information system data and add an additional weather and pavement monitoring system with a remote processing unit to enhance the RI DOT network, (2) extend and improve TRANSMAP by enhancing its data processing and analysis capability and upgrading the internet/web access to the system, (3) continue the development of the thermal energy balance model by linking it with monitoring station data to allow forecasting of road conditions at selected locations, (4) finalize access to EPA and NOAA's ALOHA contaminant transport model to allow users to predict the atmospheric plumes and zones of potential health hazards from highway spills of hazardous chemicals, (5) extend the system to allow the routine import of GIS data, and (6) to initiate the transfer of the technology developed in this project to private industry for commercialization.</p> <p>The basic framework of TRANSMAP and its associated data, map, and web servers has been constructed, implemented and tested. The system is fully operational, with access to a variety of existing, real time meteorological and marine measurement systems and is currently undergoing beta testing. The system allows the user an extensive suite of tools to analyze data being collected or archived in the data base and allows routine access to GIS bases. A thermal energy balance model, that provides real time forecasts of the temperature profile in the roadbed, and a hazardous chemical spill model, that predicts the zone of concern for an evaporative plume from land-based spills of hazardous chemicals, were developed/implemented and fully integrated within TRANSMAP. TRANSMAP has been presented in a wide variety of professional forums to generate feedback on its basic architecture and implementation. The web based version of the system is currently operational and its ability to meet user needs evaluated.</p> | | | |
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1. BACKGROUND AND STUDY OBJECTIVES

The broad goal of the present project is to develop a fully integrated real time monitoring and modeling system to provide environmental and pavement condition data for highways and waterways in Rhode Island. The system, called **TRANSMAP** (Transportation Mapping and Analysis Program), features an open architecture, industry standard software tools and modules, an embedded geographic information system (GIS), standardized data handling protocols, an environmental data analysis and presentation system, and access for linking of models and management tools. The principal users of the system are anticipated to be transportation system managers who are responsible for collecting and analyzing real-time, environmental information in support of decision making for road treatment (de-icing), ferry and associated terminal operations, shipping, environmental protection (oil and chemical spills, combined sewer releases), and recreational boating. Integration of weather information from both land and sea stations will substantially augment the available meteorological databases for coastal regions and help to better understand the spatial and temporal structure of the wind and air temperature fields. The specific objectives of the project are to (1) develop an integrated system for monitoring and forecasting of environmental conditions on Rhode Island highways and waterways in support of the Rhode Island Department of Transportation (RI DOT) and the transportation community, (2) implement, test, and evaluate the performance of this system for land and water based stations in Rhode Island, (3) transfer the data products and forecasts to interested RI DOT operations staff, major transportation user groups, and the public, and (4) transfer the system for commercialization by private industry.

The annual report for the first phase of the project (Spaulding et al., 2001) provides an overview of the system and its basic architecture; preliminary application of the system to Rhode Island highways and waterways, including basic system set up, data sources available, and preliminary results of the implementation; and a summary of planned activities for the second and third year of this three year project. The present report focuses on the work accomplished during the second year, or Phase II, of the study. The principal tasks for the second year were (1) to complete access to the RI roadway weather information system data and add an additional weather and pavement monitoring system with a remote processing unit to enhance the RI DOT network, (2) extend and improve TRANSMAP by enhancing its data processing and analysis capability and upgrading the internet/web access to the system, (3) continue the development of the thermal energy balance model by linking it with monitoring station data to allow forecasting of road conditions at selected locations, (4) finalize access to EPA and NOAA's ALOHA contaminant transport model to allow users to predict the atmospheric plumes and zones of potential health hazards from highway spills of hazardous chemicals, (5) extend the system to allow the routine import of data, and (6) to initiate the transfer of the technology developed in this project to private industry for commercialization.

Chapter 2 of this report presents the work accomplished on each of the above objectives during the Phase II effort. A separate section is devoted to each major objective. Chapter 3 provides the study conclusions and recommendations.

2. ADVANCEMENTS IN TRANSMAP AND ITS APPLICATION

In overview, **TRANSMAP** is a personal computer-based system and consists of environmental monitoring stations, a geographic information system, data processing and analysis tools, and environmental nowcasting and forecasting models. **TRANSMAP** allows the user to collect, manipulate, display, and archive environmental data through embedded environmental data management tools (e.g. time series analysis including filtering, statistical analysis, power spectral analysis, and harmonic analysis) and a geographic information system. Data collection can be either by conventional instrumentation or through a real time monitoring system using radio/satellite telemetry, cell phone, or Internet communications. The system also allows access to environmental models. In its present implementation, a thermal energy balance model and a highway contaminant (hazardous chemical) spill model can be accessed through the user interface. **TRANSMAP** operates in Windows NT[®] or Windows 2000[®], is controlled by pull down menus, and makes extensive use of color graphics to display results of data analysis and model predictions. The software is designed using a geographically oriented, open architecture making applications to any geographic area simple and fast (Spaulding and Howlett, 1996). Additional information on the system is given in the Phase I report (Spaulding et al., 2001).

In the presentation to follow improvements and enhancements made to **TRANSMAP** during the second year of the study are provided. These are organized by major tasks.

Access to RIWIS data and enhancement of network

Access to data collected by the Rhode Island Department of Transportation (RI DOT) Road Weather Information System (RIWIS), as noted in the Phase I report, was substantially hampered by a series of technical problems and issues related to the proprietary nature of the system software. Working with RI DOT and Surface Systems Inc. (SSI) (manufacturer of the RIWIS system and instruments) personnel these issues were finally resolved and local access (at RI DOT) to the RIWIS data was achieved in May 2001. Remote access to the RI DOT RIWIS data server was achieved via modem. This approach has proven slow, time consuming, and costly given the need to maintain a continuous connection between the **TRANSMAP** and RIWIS data servers in order to obtain the data in near real time. Web based access was explored but deemed inappropriate given issues related to the firewall protection on the RI DOT computer network and the processor speed of the main RI DOT RIWIS server. A solution was for RI DOT network system administrators to set up an automated FTP (File Transfer Protocol) of the weather and roadway data. An obvious drawback to this approach is that the RI DOT system administrators do not note failures of the file transfer process and the automated FTP procedure does not include provisions to recover automatically. In these cases, subsequent file transfers are precluded until they are notified (by participants of the present project) of the failure and can reset their system. To overcome this problem, software was developed to accomplish the file transfers. The software operates on the RI DOT RIWIS server and initiates a recovery process in the event of a failed file transfer (due to loss of Internet connection, log-on failure, etc.). Due to the software's built-in recovery features, it will continue to attempt the file transfer until success is achieved. Testing of the software is presently being conducted. At this time the tests have been limited given the fact that RI DOT often takes the system or individual monitoring sites offline during the summer months, since the data is not used and to allow for system maintenance.

An additional weather station, located on the main campus of the University, at the turf building, has been added to the system. The site is adjacent to the University's long-term weather monitoring station. The site includes a meteorological tower with wind speed and direction sensors. Measurements of soil moisture and temperature are also being made. Data is currently available locally. High-speed Internet access to the site awaits installation of a fiber optic line to the building by the University.

Extensions and improvements to TRANSMAP

Extensions and improvements to the personal computer and web-based versions of **TRANSMAP** were performed during this study as part of the second major objective. The major advances are presented here. The presentation begins with the basic architecture of the system and then goes on to highlight advances in the personal computer and web versions of the system.

Basic system architecture

The **TRANSMAP** system is currently setup for operation on three personal computers (PC) that are configured as servers, as shown in Figure 1. The data server (DS) retrieves, archives, and manages data from a variety of sources. Data sources might include typical monitoring systems consisting of environmental monitoring stations that relay data via radio, satellite, telephone, cellular, Internet, serial or other communication protocol to a base station. Data might also be obtained from existing environmental monitoring systems (e.g., NOAA PORTS, see Spaulding et al, 2001 for a detailed description of these data sources) that are updated in real time on an external server accessible via modem or the Internet. The data server implements a metadata structure for each data source from which it retrieves data (e.g., NOAA PORTS, RI DOT RWIS, etc.). Attributes describing the data source, such as the name of the source (i.e., name of the institution or organization operating the environmental system), geographic coverage of the system, individual monitoring sites existing within the coverage area, electronic sensors located at each site, and the individual data channels of each sensor are stored within individual nodes of the metadata structure. Instructions used by the data server for accessing and downloading environmental data (e.g., communication protocol, server IP address, telephone number, username and password, etc.) are completely defined within the structure of the metadata object. The metadata structure offers a common protocol for describing each source of environmental data, thus providing efficient access to attributes and properties for individual or multiple nodes and subsequent transfer of the information to the web server or **TRANSMAP** clients. In addition, the arrangement permits quick and economical access to specific sets and subsets of environmental data. Further details of the metadata structure and advantages of its use are provided below.

The main function of the data server is to automate real time access to external sources of environmental data and then perform the operations to retrieve, index, and archive the data. The data server can be setup to retrieve data in real-time or according to a predetermined schedule, as determined by the system operator. Once data is retrieved and archived, ensuing actions by the data server include notifying the web server and **TRANSMAP** clients of the existence of new data and then distributing the data to the web server and clients. System operators manage data access through the data server and may therefore set access permissions for individual data sets. In this manner access to confidential data may be restricted so that only those clients with specific permission can access the data.

The map server (MS) handles all the mapping and geographic information system tasks for the **TRANSMAP** system. Map server technology drives the interactive GIS functionality available on the **TRANSMAP** web site. Visitors to the **TRANSMAP** web site may view much of the GIS information that has been integrated within the system for this project. Presentation of GIS information on the web site may be customized by public users through common GIS functions such as zooming, object interrogation, panning/re-centering, and control over the visibility of individual layers of information.

Implementation of the map server extended the initial implementation of **TRANSMAP**'s geographic information system to utilize the GIS engine used in ARC/INFO and ARC/VIEW (developed by Environmental Systems Research Institute, Inc. (ESRI)). Integration of the ESRI GIS engine facilitates ingestion of GIS information in a variety of common formats including ESRI SHAPE files and coverages, CAD formatted files and many standard and geo-referenced image formats. Direct use of GIS information layers from RIGIS, MASS GIS and the Connecticut GIS system (for the present project's geographic operational area) is achieved using the ESRI GIS engine without the need for an intermediate import process.

The web server (WS) is responsible for receiving all initial requests from web visitors and **TRANSMAP** clients and coordinating operations supporting these requests. As part of these operations, the web server hosts the **TRANSMAP** web site and continuously updates the web pages of the site to present new environmental and GIS data. In this manner, appropriate modifications are made to the web pages whenever a map or data server receives new information and notifies the web server of its existence. For example, the latest weather conditions for six environmental monitoring sites operated by the NOAA PORTS system in Narragansett Bay are presented on the **TRANSMAP** web site. The information is updated automatically, in real time, every six minutes (i.e., the sampling rate maintained by the NOAA PORTS instrumentation). One would correctly note that weather information from the RI DOT RWIS is not presented on the **TRANSMAP** web site. RI DOT has not provided permission to allow public access to their data and thus the data has been appropriately flagged as private within the metadata structure of the data server. The web server can also obtain model predictions from the map server and present the predictions, overlaid on a map, on the web site.

The current system is configured for operation on three separate personal computers (PCs), making the separation of functionality clear. The system however is scalable and hence could be operated in a variety of multi-server/platform configurations (Figure 2). These might include all servers (i.e., WS, DS and MS) operating on one PC or on a networked system with multiple data and map servers accessible by the web server. To communicate with each other the web, data, and map servers require only a communication path utilizing TCP/IP protocol. This arrangement allows the servers to be located in different geographic locations and even on different network domains. Multiple map and/or data server configurations offer increased flexibility and efficiency in downloading and accessing information. Such scalability allows for future expansion of the existing system and application to future large-scale systems, without sacrificing efficiency. For example, one might expect access to environmental data from additional data sources to occur in the near future thus increasing the bandwidth and processing time required by the single data server presently in operation. Additional data servers would allow the tasks performed by the data server to be split between the two (or more) data servers, thereby reducing bandwidth and processing requirements for each individual server. In a multiple server configuration, requests received by the web server for a specific set of environmental data would be routed to the appropriate data server. The web server maintains information on the operational status of each data and map server (i.e., server is online or offline, data availability, etc.) thus permitting the web server to correctly respond to TRANSMAP clients if a request cannot be completed.

TRANSMAP is designed specifically for personal computer platforms running Microsoft Windows NT[®] or Windows 2000[®]. A minimum CPU speed of 350 MHz is recommended, along with 256Mb of RAM memory and sufficient storage on fixed disks to install the application and base files. Exact disk space requirements depend on the level and extent of GIS and environmental data sets included in the installation and those to be supported in the future. In order to access data from external sources (e.g., NOAA PORTS, RI DOT RWIS, etc.) access to the Internet is required. **TRANSMAP**'s web site is hosted on a Windows 2000[®] Server platform running Internet Information Services (IIS). Operation of **TRANSMAP**'s map/data/web server applications requires operation on Windows 2000 Server[®] with IIS.

TRANSMAP utilizes a number of programming technologies to achieve high-level functionality for its various components. The graphic user interface (GUI) has been developed in Visual Basic and is tightly integrated to dynamic link libraries (DLL's) containing data analysis and handling tools, developed in Visual Fortran. A variety of ActiveX controls (OCX) are utilized in the development of the GUI, with each providing a specific set of functions for the programmer. For example, ARCVIEW geographic information system functionality is embedded in **TRANSMAP** through Map Objects OCX developed by ESRI. Numerical models, such as the roadway condition prediction model (thermal model described below) are coded in Fortran. Externally linked models, such as ALOHA, were developed independently of this project, with the source programming language typically being C, FORTRAN or Visual Basic.

Data structure and analysis tools

In the Phase I version of **TRANSMAP** each data set was handled in the format received. This procedure is reasonable when the number of data sources is limited but becomes problematic when a large number of data sources are involved. To address this issue a custom, metadata format was developed and is used by **TRANSMAP** to manage and archive historical environmental data. Figure 3 shows the standard metadata tree structure, which at the highest level is organized according to the source of the data. The next levels, in order, are location or coverage, instrument site, instrument type/name, and instrument channel. The data tree structure for the Rhode Island Road Weather Information System (RWIS) is shown. In the example given, the coverage levels are noted for Rhode Island roadways. Block Island, Westerly, Route 95 and Civic Center, and Route 24 and Main Street in Middletown monitoring stations are shown. These represent the site level in the metadata structure. At the instrument level, roadway surface and subsurface sensors along with meteorological sensors are noted. Finally the channels containing roadbed surface and subsurface temperature, precipitation rate and level, chemical percent, wind speed and direction, and air temperature are shown.

Implementation of this basic data architecture, as displayed in the data server opening screen, is presented in Figure 4 for the Conimicut Light station in the Narragansett Bay, Physical Oceanographic Real Time System (PORTS) system. The left panel shows the data structure for **TRANSMAP**, beginning with the local data server and branching to the data sources, then to data coverages, and finally to the level of the monitoring sites. The center panel shows the sensors at the selected site (i.e. Conimicut Light) and the right panel the status of the various

channels, in this case for the meteorological sensor. Green/red indicate that the sensor is online/offline or functioning/not functioning. The administrator may add new sub-nodes or delete existing nodes by right clicking a node with the mouse cursor and selecting the appropriate action from the menu displayed in response to this action. Properties for individual nodes may also be accessed in this manner and are presented in a property dialog window. The properties may be modified if an authenticated administrator is accessing the properties dialog, otherwise the properties are presented to the user but cannot be altered. The data format was designed to be flexible and scalable, to allow each node to contain property structures specific to that node, to improve data handling and transfer, to allow seamless integration for a variety of data structures (i.e., grid data, single point time series data, non-stationary data, etc.), to minimize storage requirements, and to facilitate transfer of data products to real time applications and the web. **TRANSMAP** also supports a variety of common formats allowing users to export data for independent use.

To provide the reader with a better sense of **TRANSMAP**, the basic structure, in the most recent implementation, is summarized below. Figures are provided as appropriate to support and clarify the summary.

Figure 5 shows the opening screen for **TRANSMAP**. The center panel displays a map of the geographic location for which the system is currently operational. The user can control the specific geographic area and resolution, within a given geographic location, by creating a window, zooming in or out, or by point-to-point panning. These features are available by use of a pull down menu, located under *Zoom* on the upper level, tool bar. The geographic location, base map, and display settings can be altered by selections under *File*. By resetting the geographic location the system can be structured for operation at any location in the world and at any scale (domain size). Available layers in the GIS are provided on the left panel. Individual layers can be turned on or off in any sequence or pattern and may be reordered to clarify the presentation. Other GIS tools to add/move or delete objects, create/import or delete layers, select alternate GIS databases, or to link to other GIS databases are provided under the *GIS* menu option.

The right panel of the screen shows the names of stations currently accessible by the system. Following the metadata protocol, the lower two levels of the data tree (site and instruments) are displayed in this panel (e.g., RI DOT road weather information system sites, PORTS sites, URI Narragansett Bay Sampling sites, COFS (output of the NOAA, National Center for Environmental Prediction (NCEP) Coastal Ocean Forecast Model System (COFS) for the US east coast)). Clicking on a site icon in the data tree expands the tree to display the individual instruments for the selected site. Clicking on any instrument icon will display a graph and analysis window for that instrument. In the graph and analysis window, access to the lowest level of the metadata structure (i.e., the data channels) is provided. Selection of any data channel provides direct access to the underlying data including all data currently available in the system. As an example, Figure 6 shows the data stored for the pavement surface temperature channel from late March through the end of September 2001 for the RI DOT RWIS sensor located at the intersection of Routes 95 and 102. The upper left panel shows the selected data channel and graph display options. The middle section, available data analysis options, and the lower panel the statistics of the data (number of points, mean, minimum, maximum, average and standard deviation, variance, skew, and kurtosis). The temperature time series is shown in graphical form in the right panel. Pointing the mouse at any location on the screen automatically provides the time and value of the temperature at that point. Right-clicking on the graph displays a menu with additional options including grid line visibility, font size selection, plotting method (e.g., line, point, point and line, spline, bar, area, stick or best fit), export dialog and access to the graph help system.

The user can employ a data selection procedure to display a subset of the time series. This feature is particularly useful for examining individual time periods or features of particular interest and is accessed simply by dragging the mouse cursor over the desired window to frame a rectangle. As an example, Figure 6 shows the temperature has a mean trend over monthly time scales corresponding to seasonal warming and cooling trends. There is also evidence of much higher frequency variability in the record. Using the windowing function and selecting a period of several days in July 2001 it is observed that this variability is associated with the normal day-night, heating-cooling cycle of the road surface (Figure 7). The user also has the option of selecting the units for the time access of the plot.

TRANSMAP allows the user to clean (removal of spikes) and smooth the data, remove the mean, and to apply high and/or low pass filters to the data. For the high/low pass options the user can select the cutoff frequencies for the filters. As an example, Figure 8 shows road surface temperature after low passing the data using a cutoff frequency of 0.0416 cycles per day. This filters the data to remove variations with periods less than 24 days. The

filtered data clearly shows seasonal trends related to the spring-summer heating and the beginning of autumn cooling. Use of high and low pass filters in combination has the effect of a band pass filter operation.

The user can also generate a power spectrum for the data. The power spectrum can be based either on the original or high and/or low passed data. This analysis is implemented by selecting the Plot Power Spectrum option in the graph options and then the type of windowing function to be used on the data (Rectangular, Parzen, Welch, Hanning or Kaiser-Bessel). Figure 9 shows the power spectra of the road surface temperature data displayed in Figure 6. The figure clearly shows the very large variability at one cycle per day, reflecting the significance of the day-night, heating and cooling cycle on road surface temperature.

The presentation above has displayed the capabilities of the data presentation and analysis module for road surface temperature. The system allows the user the ability to perform similar data analyses on any time series data stored in **TRANSMAP's** database. The analyses can be performed on the entire data set archived in the system or any subset of the data.

The final major category in the main menu, **TRANSMAP**, provides access to the Station Explorer, the Status Board, and Land and Marine Models. Each is described in additional detail below. Station Explorer provides an alternate path to access the data and analysis procedures accessible via the right panel of Figure 5 and summarized above. The Status Board (Figure 10) provides a summary of the most recent observations for each station/sensor that is defined in the system. Up to three station/sensors may be displayed simultaneously, with the station and sensor location description provided in the upper left corner of each pane. The time of the observation is presented next. The observations are then provided for each channel for the particular sensor. As an example, for the station at the intersection of Routes 95 and 146 the pavement sensor data (sensor 0 and sensor 1) (surface temperature, chemical factor, solution depth, subsurface temperature, freezing point, percent chemical concentration, percent ice coverage, and water level (on road surface)) and meteorological data (air temperature, dew point, relative humidity, wind speeds and directions, barometric pressure and precipitation rate) are provided. If no data is available from a sensor, or an individual sensor channel, then this is also noted. Access to other stations can be obtained by moving the slide bar on the right side of the screen. The data server automatically updates information necessary to provide the most recent observations on the status board.

The land and marine based models can be accessed through the pull down menu on the upper tool bar. Two land models are currently operational in **TRANSMAP**, a thermal energy balance model to predict the road surface temperature and a hazardous chemical model to predict the evaporative plume from a spill of a hazardous chemical. These are described in more detail in the Phase I report (Spaulding et al, 2001). Improvements made in integrating these models into **TRANSMAP** are presented below.

Output from marine environmental models can also be accessed by **TRANSMAP**. These include predictions from hydrodynamic and emergency response models. These models are run independently and the output accessed and visualized via the system. A tidal charting system is also accessible via this menu. The software allows the user to generate a tidal height versus time (one month long) calendar for any station in the database for any time. Tidal predictions can be based on water level data collected by the system (e.g. via NOAA PORTS) or from a tidal harmonics database. The user can overlay predictions for up to three separate stations. Figure 11 shows sample tidal height predictions for Block Island, Newport, and Providence, RI for January 2002. The tidal charting system, based on the most recent real time data from the study area, can be used by marine transportation personnel to forecast water levels in support of shipping activities.

Web version of TRANSMAP

To provide the public access to the information being collected by **TRANSMAP**, a web based server system is under development. The web site has been designed using standard Hypertext Markup Language (HTML) protocol and Active Server Pages (ASP) technology. Javascript and Vbscript have been utilized in order to support interactive GIS functionality and real time environmental data display on the web site. The system is currently operational, in beta test form (<http://transmap.oce.uri.edu>). Development of the web-based interface is being coordinated with a similar effort funded by the EPA EMPACT program and led by the Narragansett Bay Commission. The Home page of **TRANSMAP/WEB** is shown in Figure 12 with links to home, project background, interactive GIS, models and related sites provided in the left panel. The right panel shows the home (i.e., default) page that includes the latest information from the NOAA PORTS system sensors. A map is provided

to the right and shows the locations of the PORTS and RWIS stations. Access to the GIS data can be obtained from the Map Server page shown in Figure 13. The user is given the ability to re-center the map, zoom in and out, and interrogate the map. The data layers currently supported by the map server are noted and display of individual layers is controlled by simply checking the box next to the layer name and pressing the update map button. Icon representation legends are available for individual layers and are accessed by clicking on the arrows next to each layer in the list.

The user can access **TRANSMAP's** database and display environmental data observations. Figure 14 shows observations at the Rte 195/102 RWIS site for a selected period in July 2001. The web site also has the ability to allow the user to animate model output. Figure 15 displays model predictions of the currents at the entrance to Narragansett Bay on January 10, 2001. The currents are flooding at this time with tidally driven water flow entering the lower east and west passages of Narragansett Bay.

Thermal energy balance model

During the later stages of the Phase I study a thermal energy balance model was developed. The model is based on the one dimensional, thermal energy equation and includes turbulent, sensible and latent heat fluxes between the road and the atmosphere and the net long-wave and short-wave solar radiation fluxes at the road surface. The latent and sensible heat fluxes are dependent on the wind speed, specific temperatures and humidity of the road surface and atmosphere, and the stability of the atmosphere. Total or net radiation flux is dependent on solar zenith angle, ice and snow height, effects of water vapor and cloud cover, total downward solar flux consisting of direct and diffuse radiation, and surface albedo. Model predictions include continuous vertical temperature profiles from the road surface to depths of about two meters in the roadbed as a function of time. The model also allows predictions of road icing conditions. A primary use of the model is to forecast icing of road surfaces and to provide sufficient advanced warning to allow appropriate response from road maintenance crews. A presentation of and references to the underlying model formulation, numerical solution methodology, and a sample simulation of a road temperature profile, over a typical day in January, are provided in the Phase I report.

Following model development and initial testing in Phase I the model has been fully integrated into **TRANSMAP**. Atmospheric data, necessary as input to the model, can now be directly obtained from observations in **TRANSMAP's** databases or from real time observations at any of the monitoring stations. As an alternative the user can obtain forecast information and enter this as input to the model. The thermal energy balance model can now be executed from **TRANSMAP** and model forecasts for the next 72 hours obtained. Model predictions of the heat flux terms at the road surface (total heat flux, short and long wave radiation, sensible and latent heat flux) and temperature profile within the roadbed versus time (and at the road surface) can be visualized through the user interface. Figure 16 displays the 72-hour model forecasts for the western end of the Newport Bridge starting on October 18, 2001. Model predictions were generated from input taken directly from the RI DOT RWIS station at this site. The heat flux balance is shown in the lower right panel and road surface temperature forecast in the lower right panel. Environmental conditions from the RWIS site (surface temperature, water, ice coverage, air temperature, wind speed, humidity, cloud cover, cloud type and atmospheric pressure) at the start of the forecast period are provided. For this case the meteorological conditions are assumed to be persistent over the forecast period. The model predictions clearly show the diurnal variation of the roadbed temperature in response to the day-night, heating and cooling cycle.

Improved linkages to the ALOHA model

NOAA and EPA's Areal Locations of Hazardous Atmospheres (ALOHA) contaminant transport model has been integrated into **TRANSMAP** (NOAA/EPA 1999). The model supports emergency training, planning and response tactics for personnel that respond to chemical spills and accidents. Based on user supplied information (spill parameters and weather conditions), ALOHA first predicts the rates at which chemical vapors escape into the atmosphere from broken pipes, leaking tanks, or evaporating puddles. The embedded database includes over 1000 common hazardous chemicals that are transported by land, rail, or water. The model then predicts how a hazardous gas cloud from the release will disperse in the atmosphere after an accidental chemical release. The model is ideally

suites to allow the user to predict the atmospheric plumes from highway spills of many hazardous chemicals that are transported via highways and railways.

An illustration of the use of the model for a hypothetical spill from an overturned tanker truck on Rte 1A in Narragansett, RI was illustrated in the Phase I report and the input data forms required to perform the simulations shown. Model output, in terms of the predicted area for which methane concentrations exceed the Level of Concern (LOC) (1ppm) for the spill, was demonstrated. These predictions were stored in the GIS and overlaid on the base map for the study area. The ability to use the embedded geographic information system in **TRANSMAP** to allow the user to overlay other relevant information that might be useful in responding to the spill (i.e. locations of schools in the vicinity of the spill site that might need to be evacuated) was also illustrated.

During the Phase I study the linkage between ALOHA and **TRANSMAP** required the user to perform a series of relatively cumbersome steps to provide the various input data and to display model output. These steps were straightforward for system developers but would be very difficult and time consuming for typical system users. The lack of source code for ALOHA prevented the seamless integration of ALOHA into **TRANSMAP**. As a partial solution the ability to open ALOHA as a window within **TRANSMAP** was implemented. The user could then interrogate **TRANSMAP** to obtain key input information, such as spill location (latitude/longitude) and wind speed and direction from the nearest meteorological station, and then enter this data directly into the appropriate ALOHA input form. Figure 17 shows the form used to specify the coordinates of the spill site, by identifying the source location on the base map or entering the latitude/longitude directly. Model output of the aerial location (plume) is displayed graphically by ALOHA with the extent of the plume shown along axes representing along- and cross-wind directions (Figure 18). This is a separate, stand-alone plot output from ALOHA and must be manually oriented and scaled on a map in order to make best use of the results. Access to the numerical output data from ALOHA has been achieved and **TRANSMAP** configured to automatically import, process and continually update model output and display the aerial location of the hazardous chemical plume on the GIS map of **TRANSMAP**. Interpretation of the aerial location of the plume is greatly facilitated, since the plume is drawn with the proper geographic orientation and scale. Figure 19 shows the model predictions for a spill of chlorine on Rte 1A in Narragansett, RI. Automation of this output substantially simplifies the ability of the user to visualize model output and would save ALOHA operators valuable time when responding to a chemical spill. In addition, the user can overlay other pertinent information useful in responding to the spill, such as the locations of schools in the vicinity of the spill site as shown in Figure 19. Relevant information such as the names and addresses of schools located within the chemical plume footprint are quickly extracted from **TRANSMAP**'s GIS databases and is shown for this example in Figure 20. The user can then determine the distance from the spill site to any school using standard GIS distance measurement tools and enter this information into ALOHA to determine the concentration of chlorine in the atmosphere at the school since the start of the spill. This capability is shown in Figure 21 for the Southern Rhode Island Regional Elementary School, as a result of the chlorine spill and shows that any time saved when responding to such spills can be critical.

Access to Geographic Information System (GIS) Data

In the initial development of **TRANSMAP** the user would obtain geographic information from a GIS database for the area of interest. Each data layer obtained would be processed and input into **TRANSMAP**'s GIS. Data sets initially included in **TRANSMAP** for the Rhode Island application were county and town boundaries, main and secondary roads, waterways, rivers, streams, and lakes. This capability was demonstrated in Figure 13 of the Phase I report. Taking advantage of the full implementation of ESRI's ARCVIEW GIS in **TRANSMAP** a link procedure has been developed that allows the **TRANSMAP** user to access and import any data layers in the Rhode Island GIS. These GIS data sets are typically stored in SHAPE file format. SHAPE format is a standard format developed by ESRI and used throughout the GIS community (e.g., RI GIS, MASS GIS). Other supported formats for GIS data include ESRI coverages, CAD, and standard and military geo-referenced image formats. The link procedure is sufficiently generic to allow access to GIS information systems for all sites using ArcView. In practice geographic data can now be accessed and data layers downloaded from the internet from state GIS agencies. This capability allows the user full control in accessing and displaying geographic data and eliminates the need for the system developer or a GIS expert to handle this task.

Transfer Technology for Commercialization

The first step in the technology transfer effort is to assess user needs and what the potential market for **TRANSMAP**, or its various components, might be. This effort was initiated in Phase II by presenting the **TRANSMAP** system at various technical forums. As an example, an overview of **TRANSMAP** and its current application to Rhode Island was presented at the Marine Transportation System, Research and Technology Coordination Conference, November 14-16, 2001, Washington, DC. This is one of the premiere national conferences in marine transportation systems. In addition a brief article on the system appeared in the November 2001 issue of American Society of Civil Engineering's (ASCE) Civil Engineering magazine. To obtain feedback from potential local users, oral presentations were made at the 13th and 14th Rhode Island Transportation Forums, held at the University of Rhode Island, Kingston, RI, on October 13, 2000 and October 19, 2001, respectively and also at the Narragansett Bay Commission's Seminar Series.

3. CONCLUSIONS AND RECOMMENDATIONS

Work during Phase II has led to substantial advancements in **TRANSMAP** and its application to Rhode Island roadways and adjacent coastal waters. The basic architecture of **TRANSMAP** and associated servers (map, data, and web) have been designed, implemented, and tested. The approach has proven to be robust, flexible, and scalable. Access to the RI DOT RWIS data has been achieved via FTP, allowing near real time access to this data while simultaneously maintaining the security of the RI DOT network. A new metadata structure, using a tree structure with the top level based on data source and the lowest level on instrument channel has been designed and implemented. The internal communications and data handling procedures have been designed around this structure. Applications to date, for a variety of data sources, shows that the procedure is simple to implement, allows for rapid and efficient handling of the data and is readily extendable to other data sources. The web-based version of **TRANSMAP** is currently operational in beta test mode. The system allows the public to access the environmental data being collected by the system, to display a limited set of GIS data, and to display model outputs.

Thermal energy balance and hazardous chemical models have been fully integrated into **TRANSMAP**. The thermal energy model can be opened as a window within **TRANSMAP**. The model can be initialized and forecasts made for any station, where weather data is currently being collected and forecasts of meteorological conditions are available. Tools to visualize model predictions, to include displaying time series of the various terms in the energy balance equation and the road surface temperature over the forecast period, have been developed and demonstrated. Within the limitations imposed by the lack of availability of the source code, ALOHA has been integrated into **TRANSMAP** to the extent possible. This has included using forms and the base map to facilitate entering input data and re-structuring and automating the output for direct visualization on the base map. The model predicted footprint for the impact zone is imported as a GIS layer allowing application of GIS tools to assess facilities impacted by the chemical atmospheric plume.

With implementation of ESRI's ARCVIEW GIS in the current version of **TRANSMAP** a link procedure has been developed that allows the **TRANSMAP** user to access and import any data layers stored in SHAPE file format (standard format developed by ESRI and used throughout the GIS community (e.g., RIGIS, MASSGIS)). The system also supports ESRI coverages, CAD, and standard and military geo-referenced image formats. The link procedure is sufficiently generic to allow access to GIS information systems for all sites using ARCVIEW.

The process of exploring the market for commercialization of **TRANSMAP** was initiated by a series of local and national presentations. The feedback from these presentations has led to refinements to better meet market needs.

REFERENCES

National Oceanic and Atmospheric Administration (NOAA) and Environmental Protection Agency (EPA), Areal Location of Hazardous Atmospheres (ALOHA), User's Manual, NOAA, Hazardous Materials Response Division, Seattle, Washington, and EPA, Chemical Emergency and Preparedness, Washington, DC.

Spaulding, M. L., K. Korotenko, T. Opishinski, and C. Galagan, (2001). TRANSMAP: An integrated, real time environmental monitoring and forecasting system for highways and waterways in RI- Phase I, prepared for University of Rhode Island Transportation Center, Kingston, RI, URI-TC Project 536139.

Spaulding, M. L. and E. Howlett (1995). A shell based approach to marine environmental modeling, *Journal of Marine Environmental Engineering*, Vol. 1, p. 175-198.

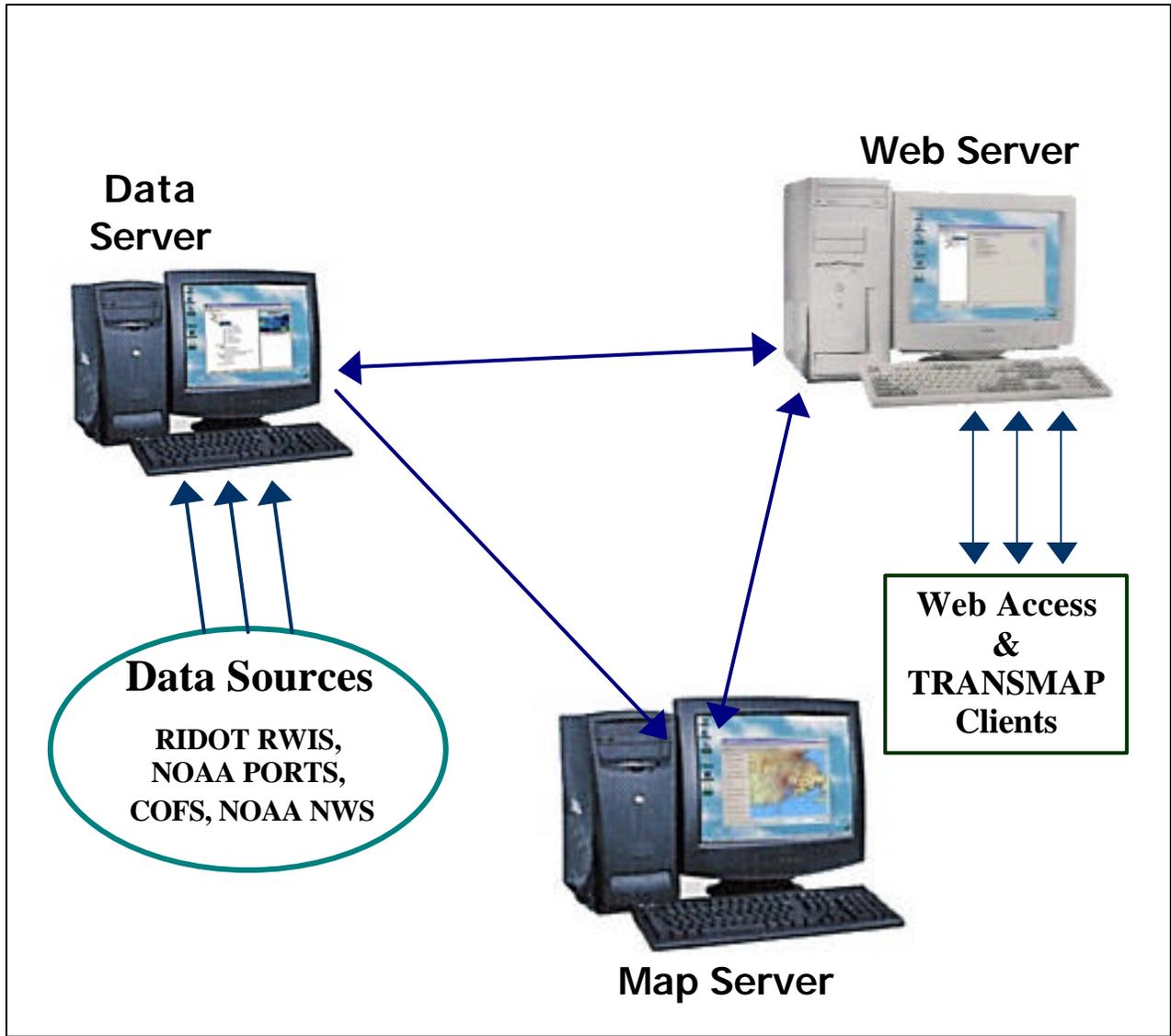


Figure 1. Diagram detailing the Web, Map and Data server architecture of **TRANSMAP**. Communication paths existing between the three servers are indicated by the lines drawn between the servers. Communication paths to external resources are indicated by grouping three arrowed lines. Arrows indicate the direction of information flow.

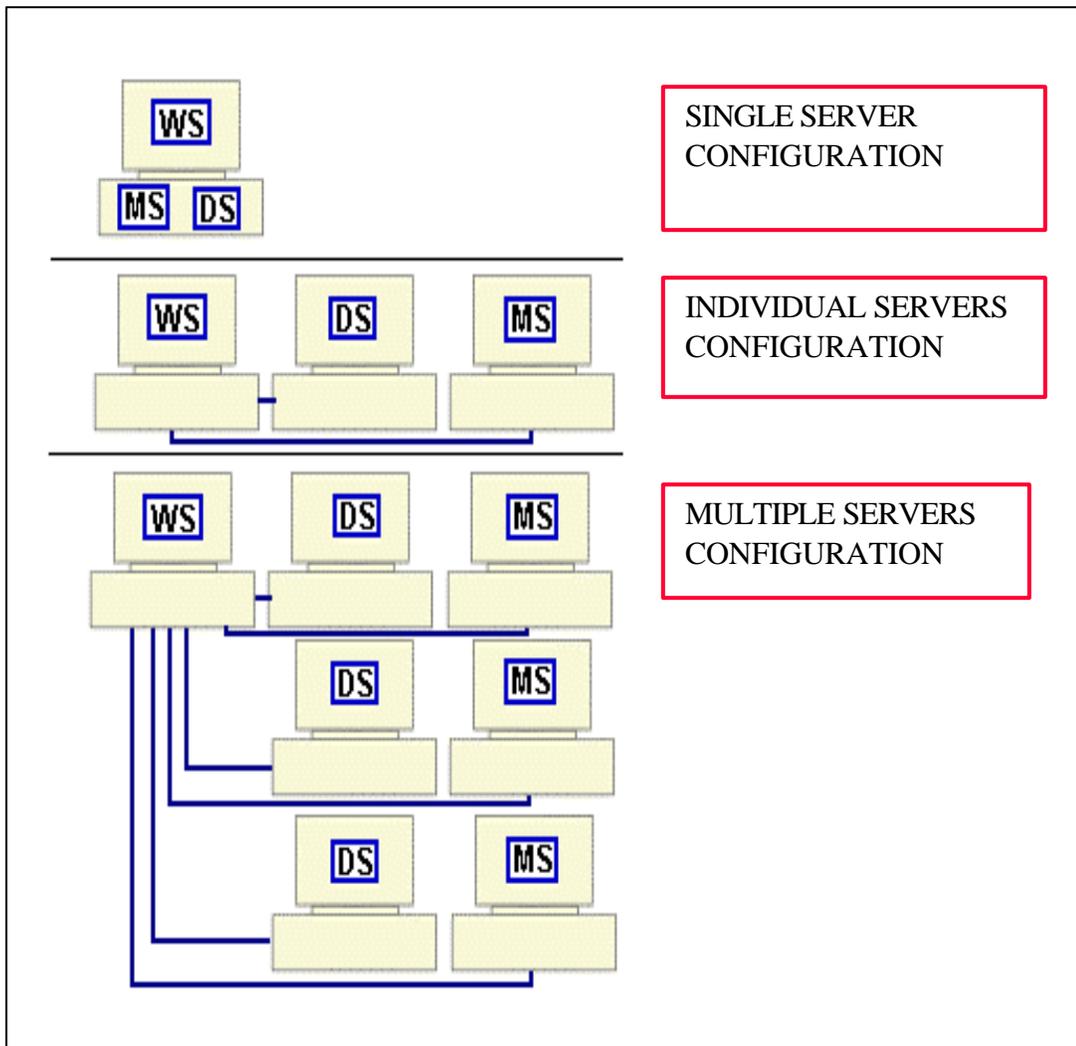


Figure 2. Scalable architecture of the web, map and data servers permits a variety of multi-server/platform configurations. Application of the system to both large and small systems, or future expansion of the existing system, is easily achieved under the present design.

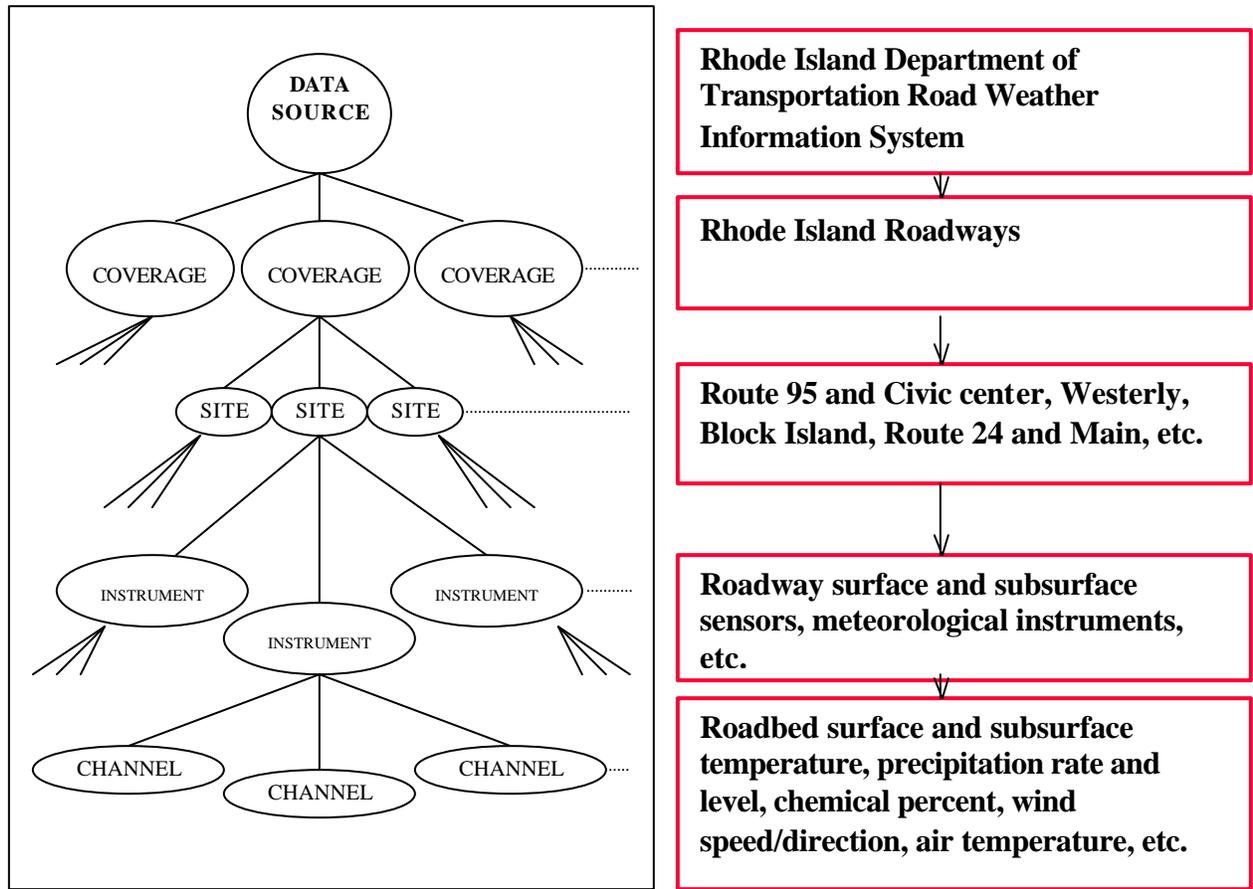


Figure 3. The tree structure depicting the hierarchy of the metadata object implemented in TRANSMAP is shown in left pane. Right pane illustrates breakdown of source data from the Rhode Island Road Weather Information System under the metadata structure.

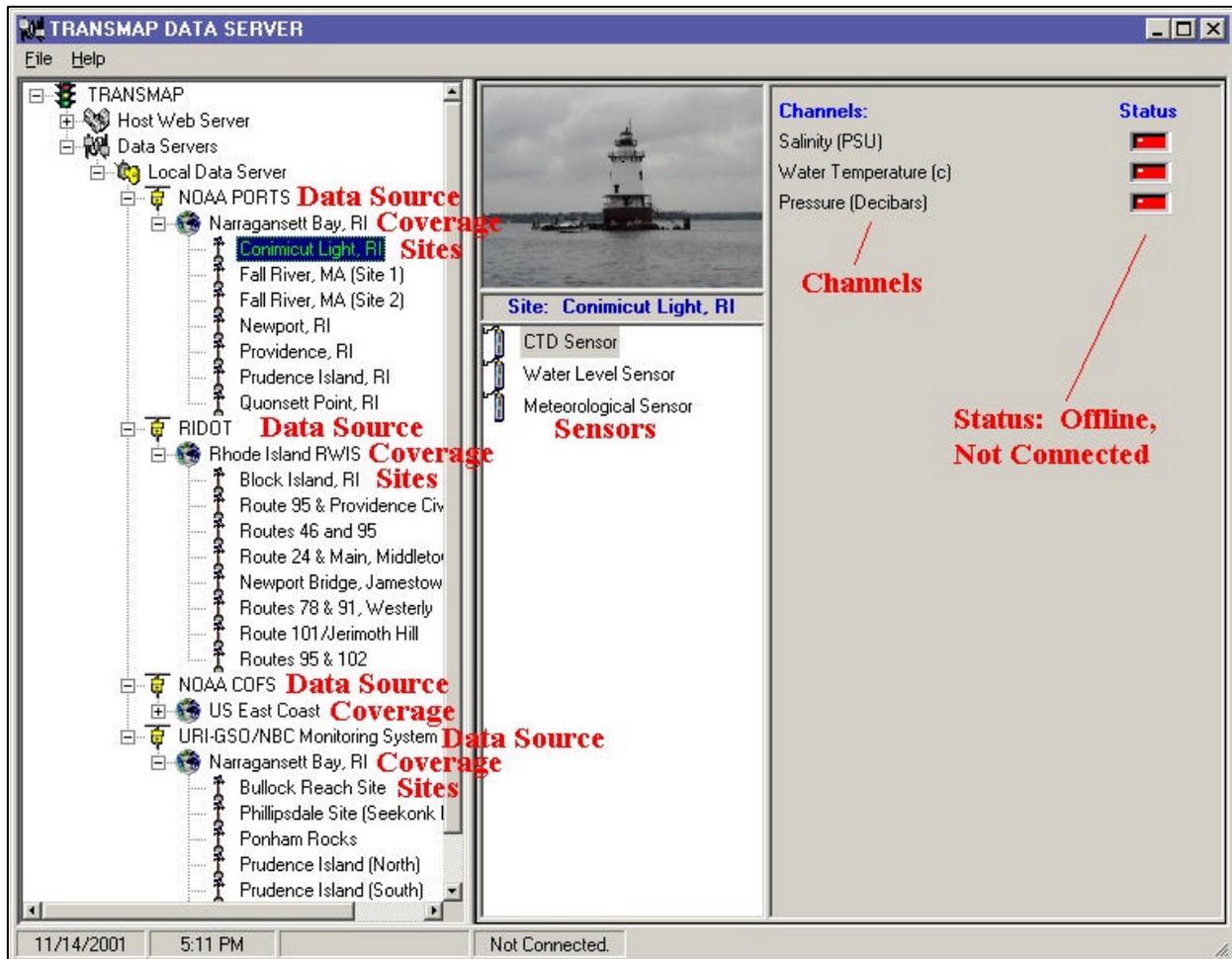


Figure 4. Application interface of the Data Server with comments inserted to identify individual components of the metadata structure. The left panel shows the various data sources (e.g., NOAA PORTS, RI DOT RWIS, NOAA COFS, URI/NBC) indexed under the local URI TRANSMAP Data Server. Appearing under each of the data source nodes are nodes defining the geographic coverages. Individual monitoring sites existing within each geographic coverage area are shown under the coverage nodes. The center panel lists sensors located at the selected monitoring site (i.e., Conimicut Light) and the right pane shows the data channels for the selected sensor (i.e., CTD sensor).

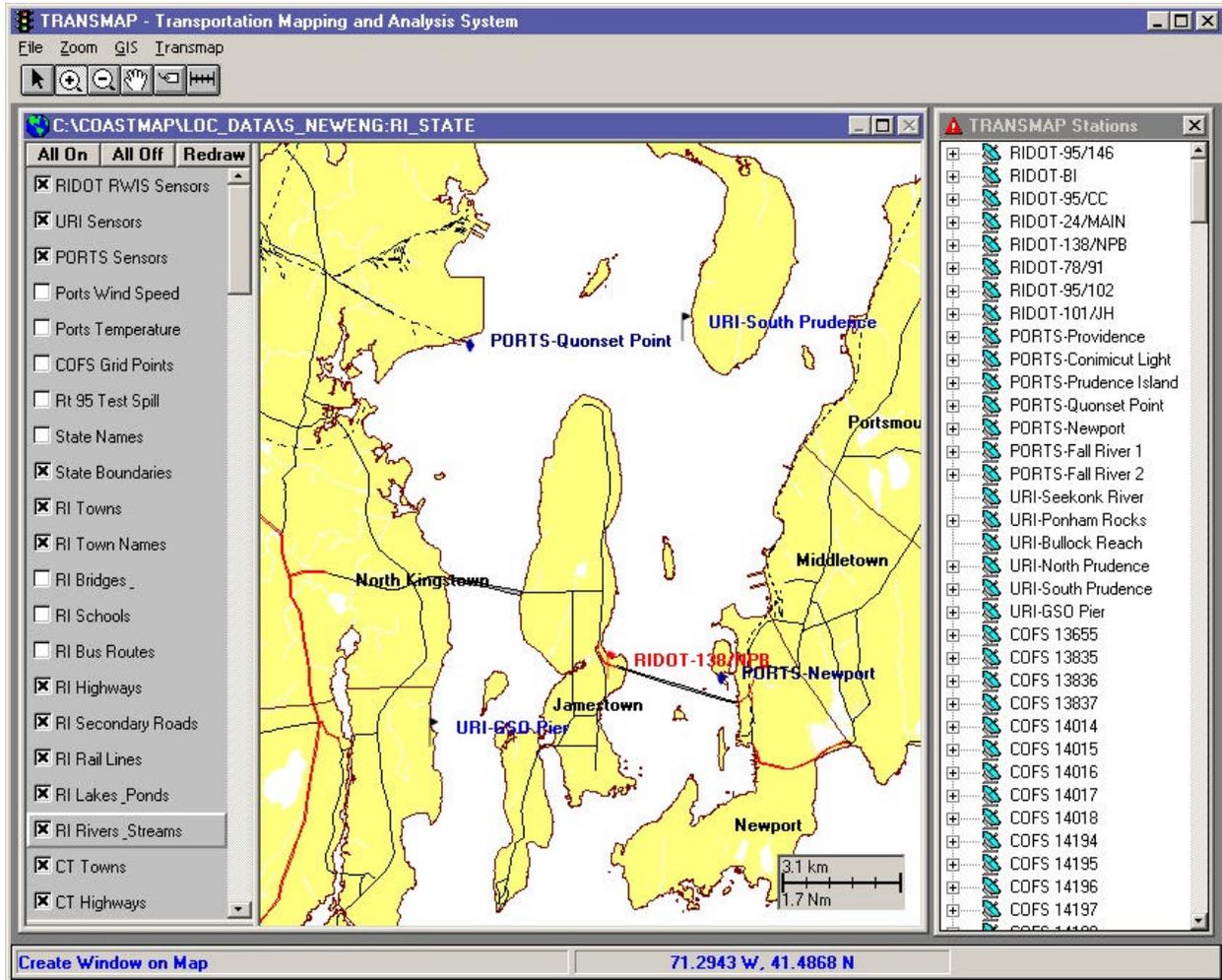


Figure 5. TRANSMAP opening screen.

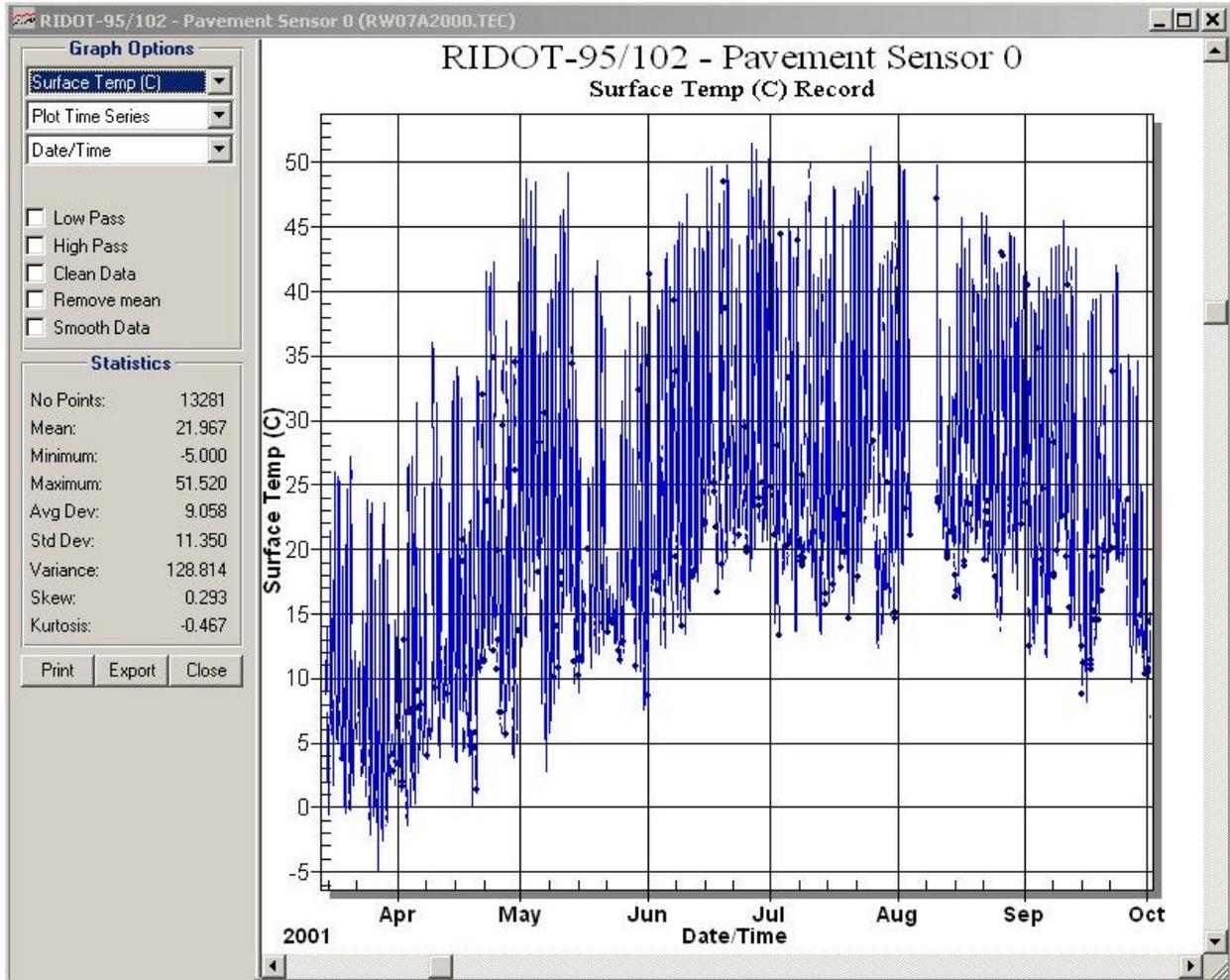


Figure 6. Road surface temperature versus time at the Rte 95/102 intersection RI DOT RWIS station., April to September 2001.

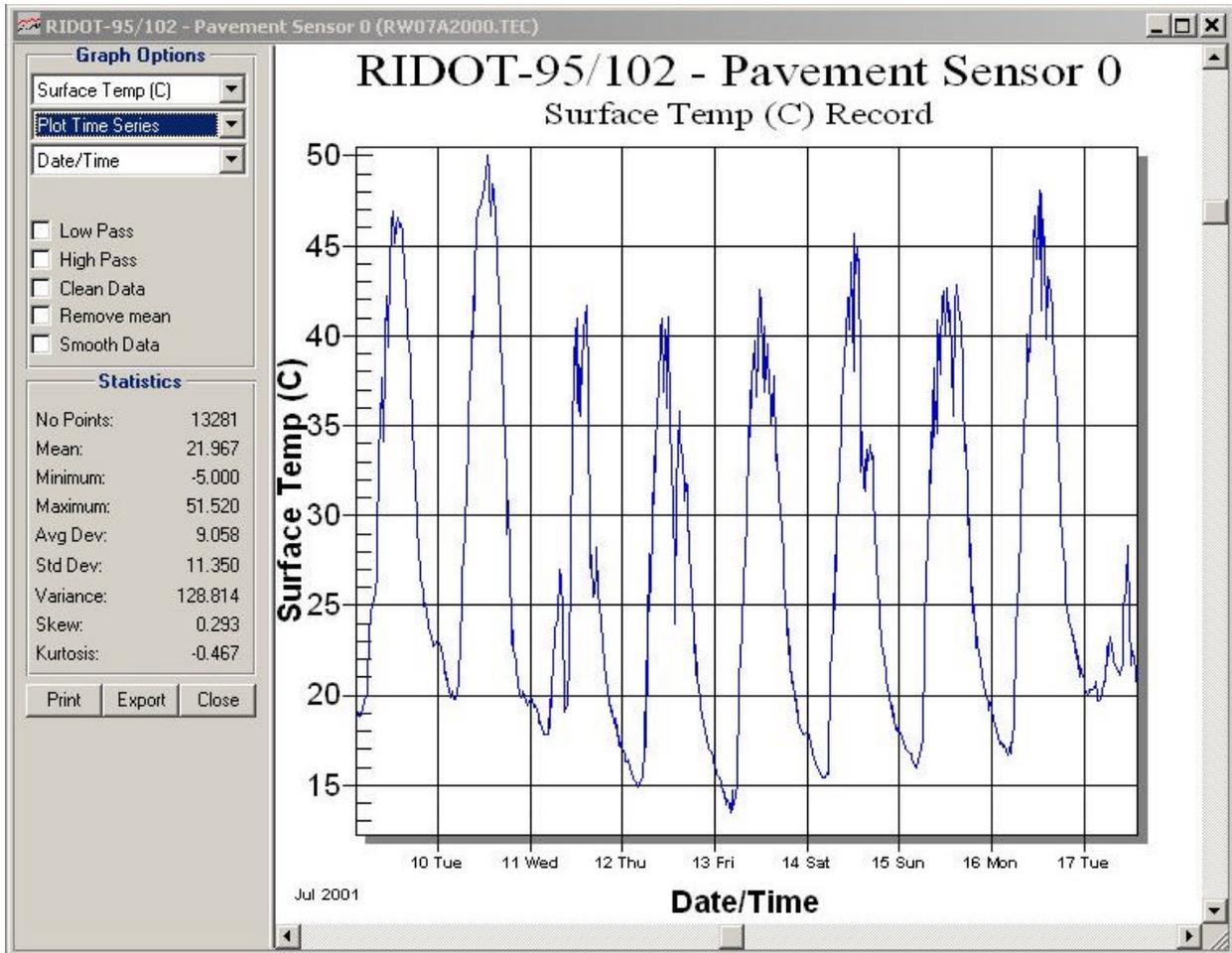


Figure 7. Road surface temperature measured at the Rte 95/102 intersection RI DOT RWIS station from July 9 to July 17 2001.

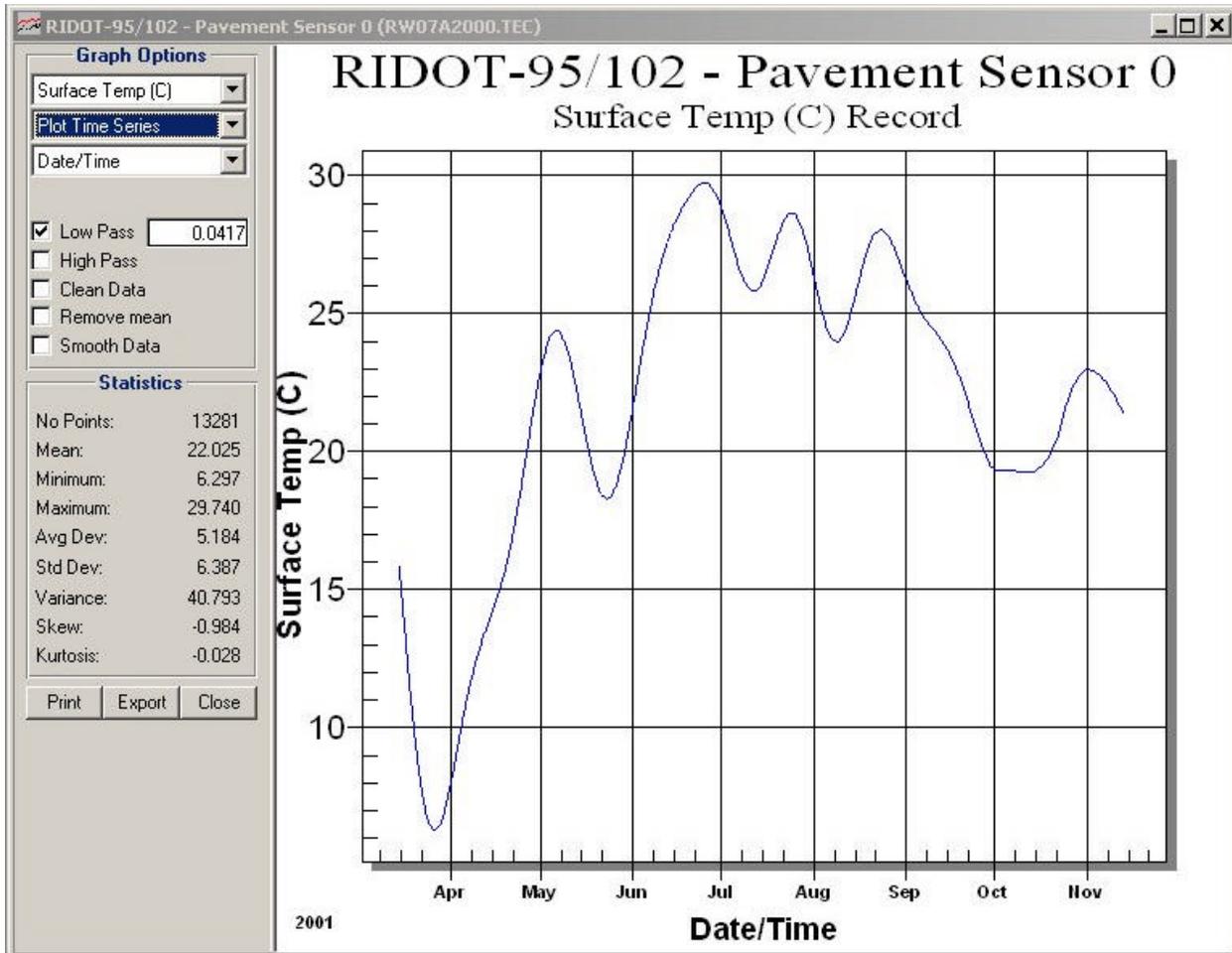


Figure 8. Low pass filter applied to the road surface temperature as measured at the Rte 95/102 intersection RI DOT RWIS station, April to September 2001. The cut off frequency for the low pass filter is 0.0417 cycles/day.

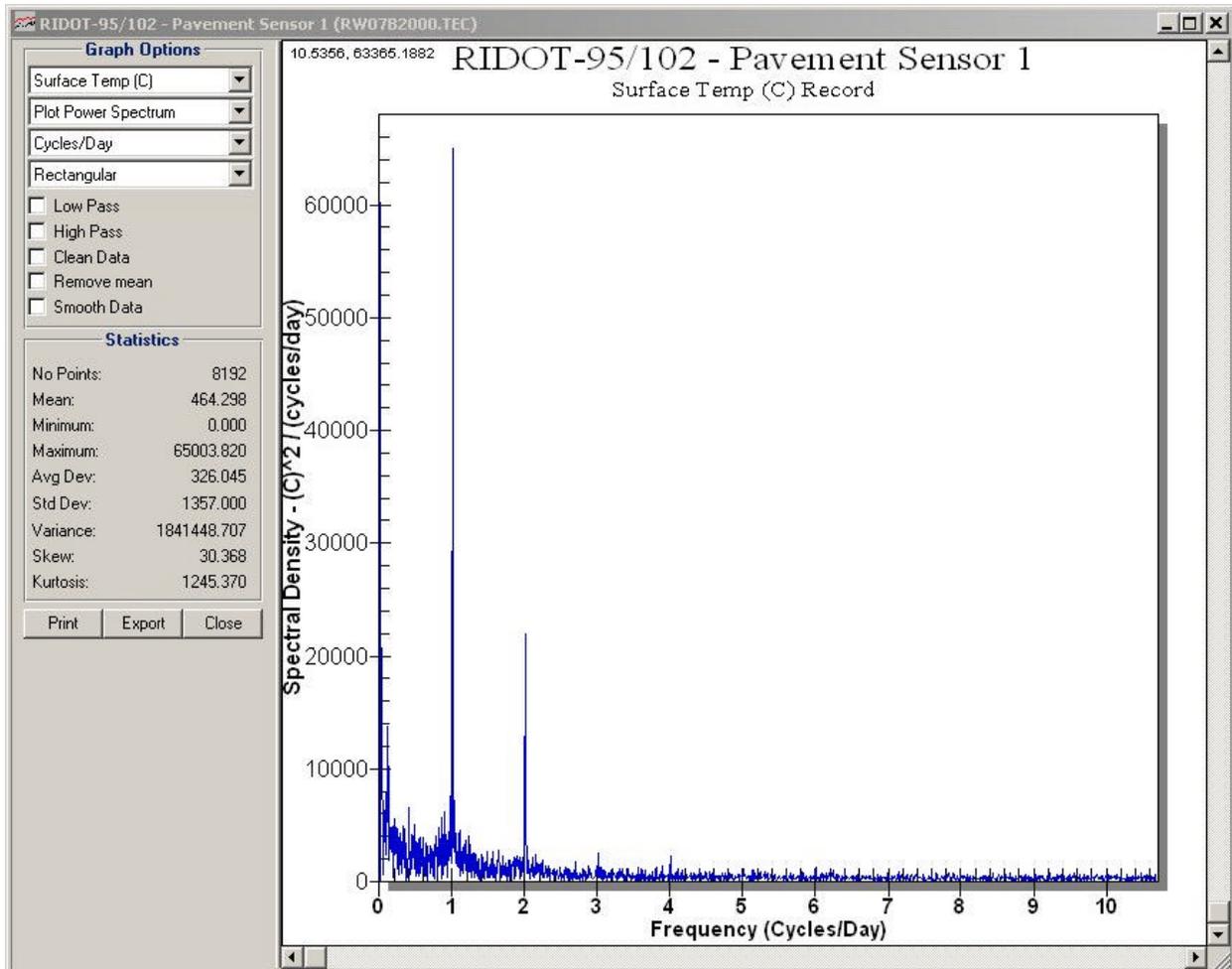


Figure 9. Power spectra of the road surface temperature versus frequency at the Rte 95/102 intersection RI DOT RWIS station, April to September 2001.

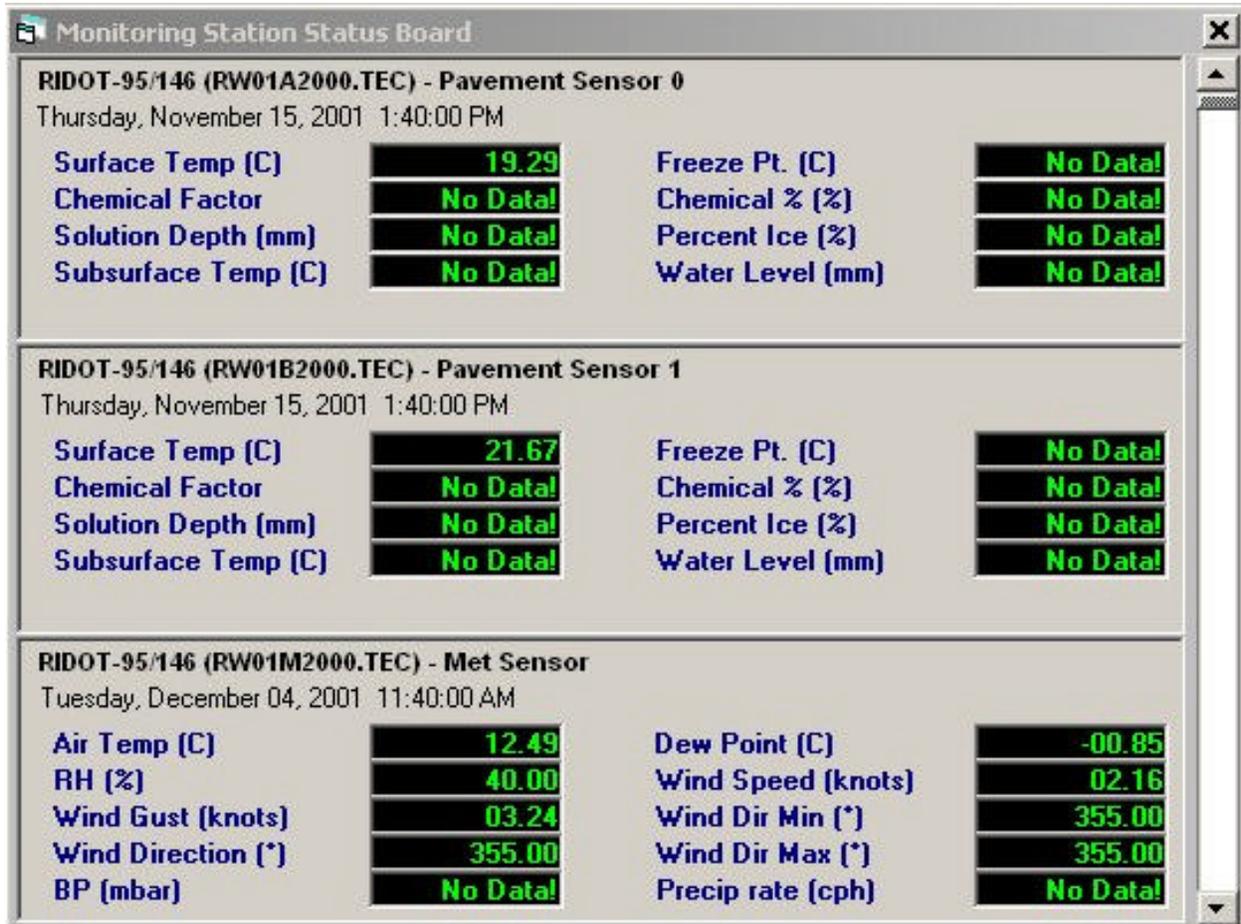


Figure 10. TRANSMAP observation status board displaying present environmental conditions measured at the intersection of routes 95 and 146 by the RI DOT RWIS system. The vertical bar on the right side of the display is used to scroll the display to present conditions at other monitoring sites.

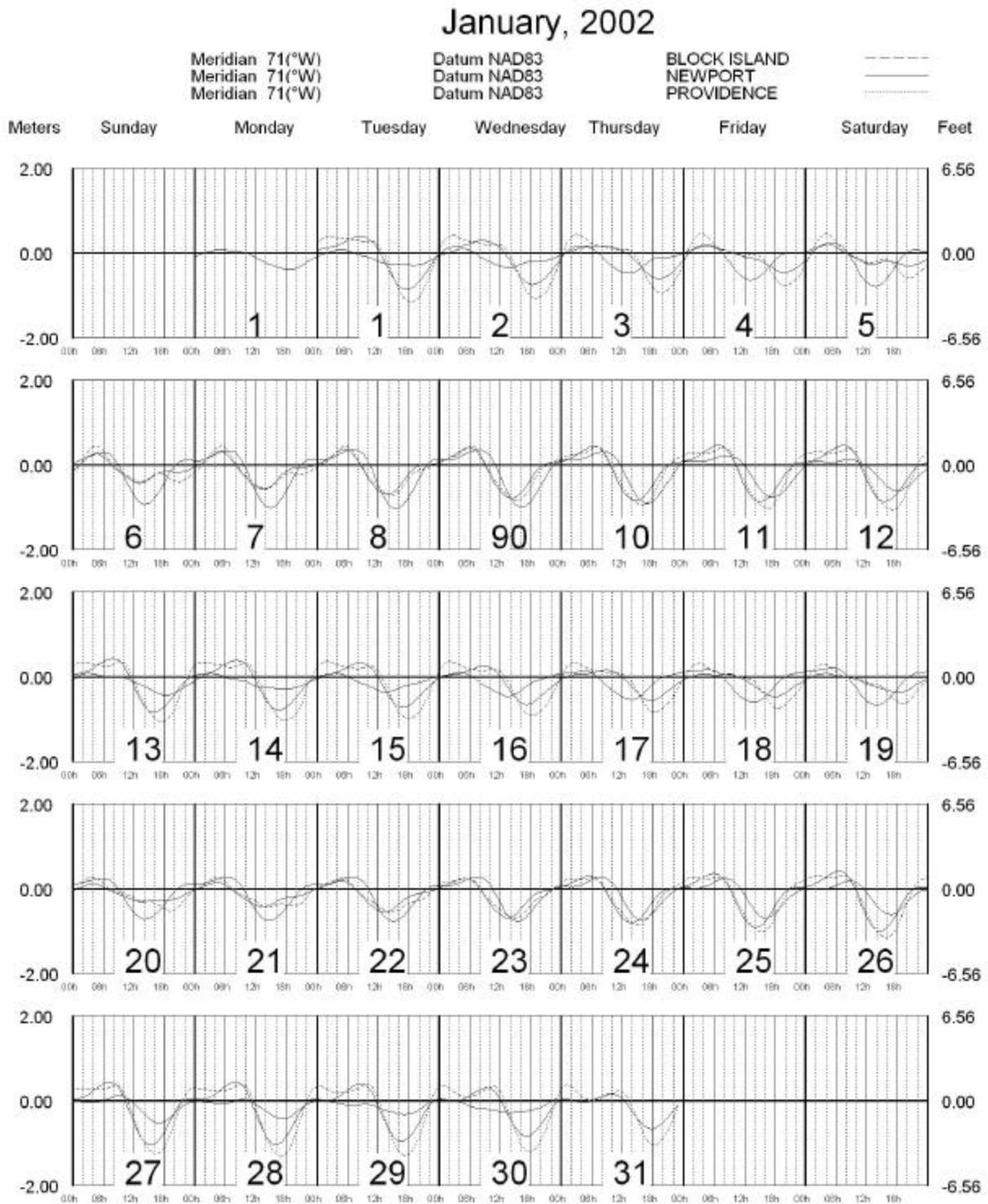


Figure 11. Predictions of the tidal height versus time for the month of January 2002 for Block Island, Newport, and Providence, RI observations sites.

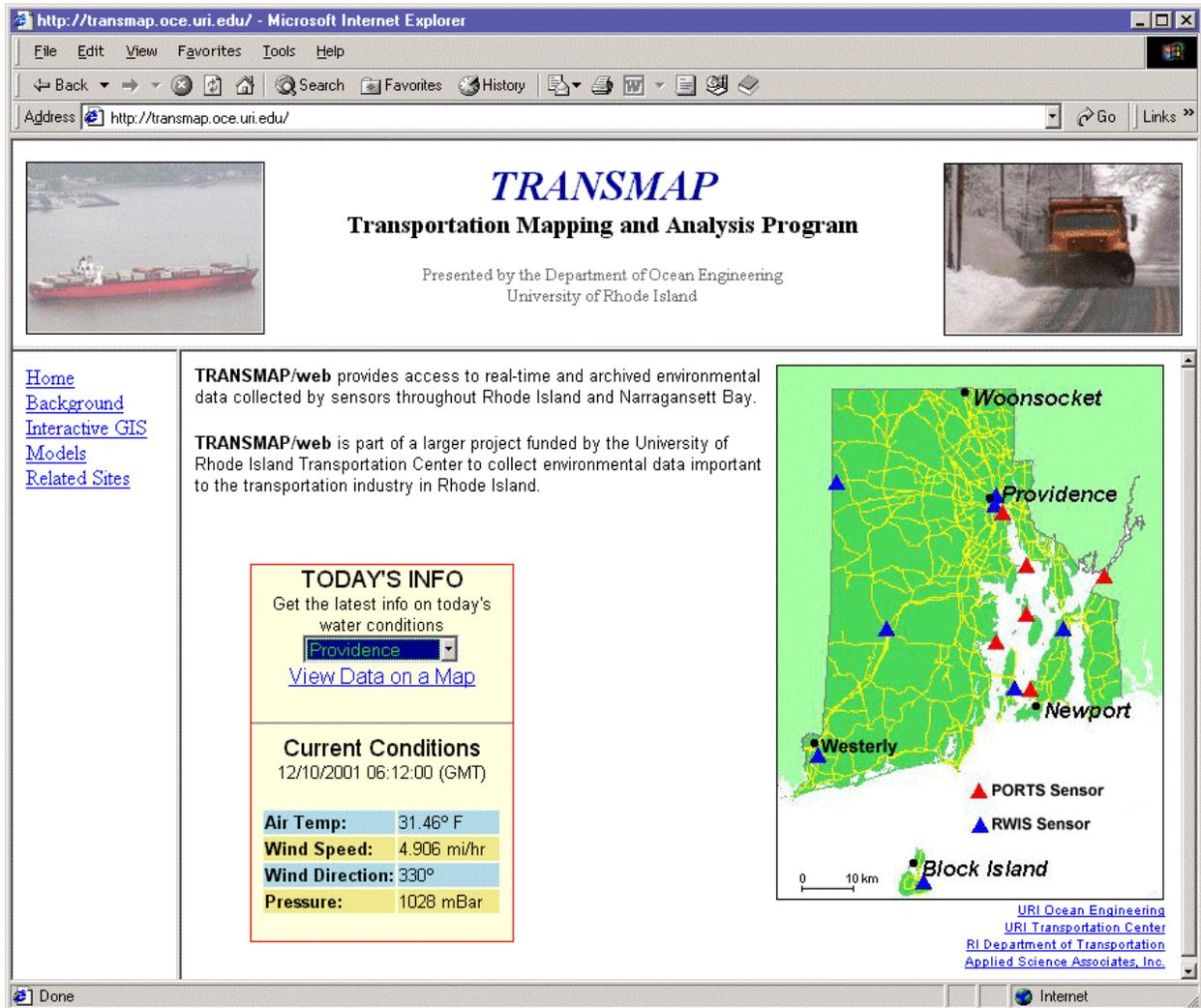


Figure 12. Opening screen for the TRANSMAP web site.

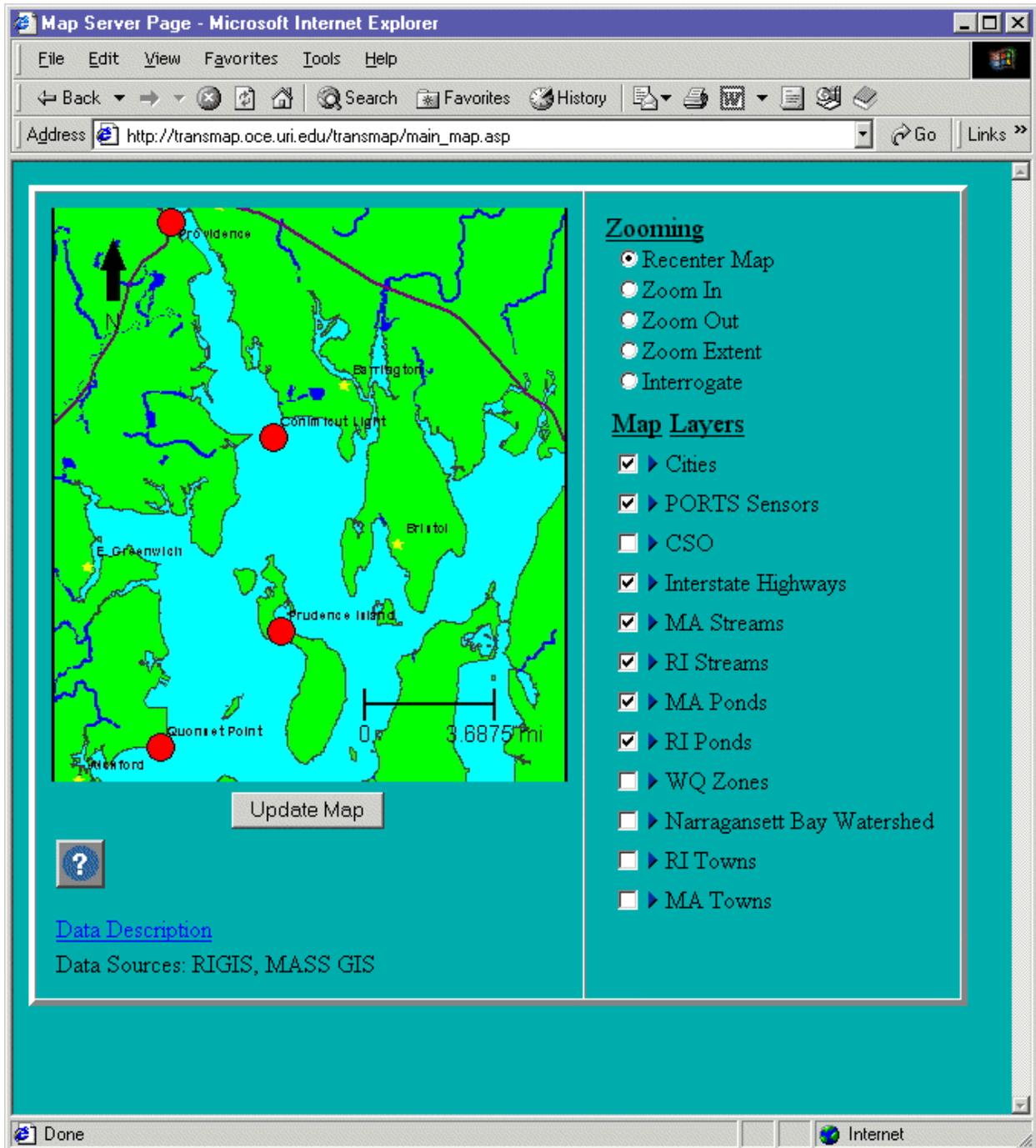


Figure 13. TRANSMAP/WEB interactive GIS.

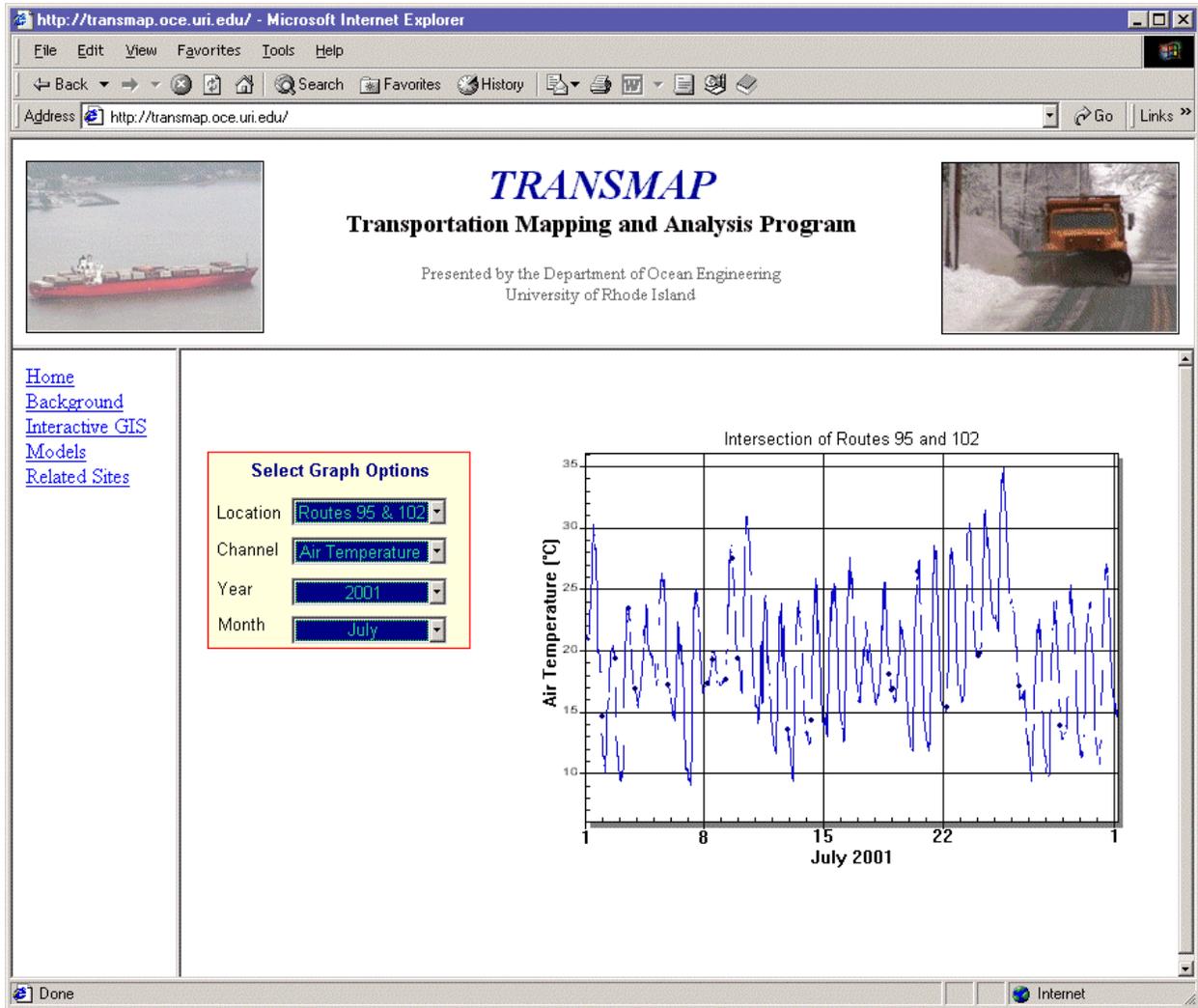


Figure 14. Time series of air temperature at Rte 95/102 for the month of July 2001 as displayed on the web site.

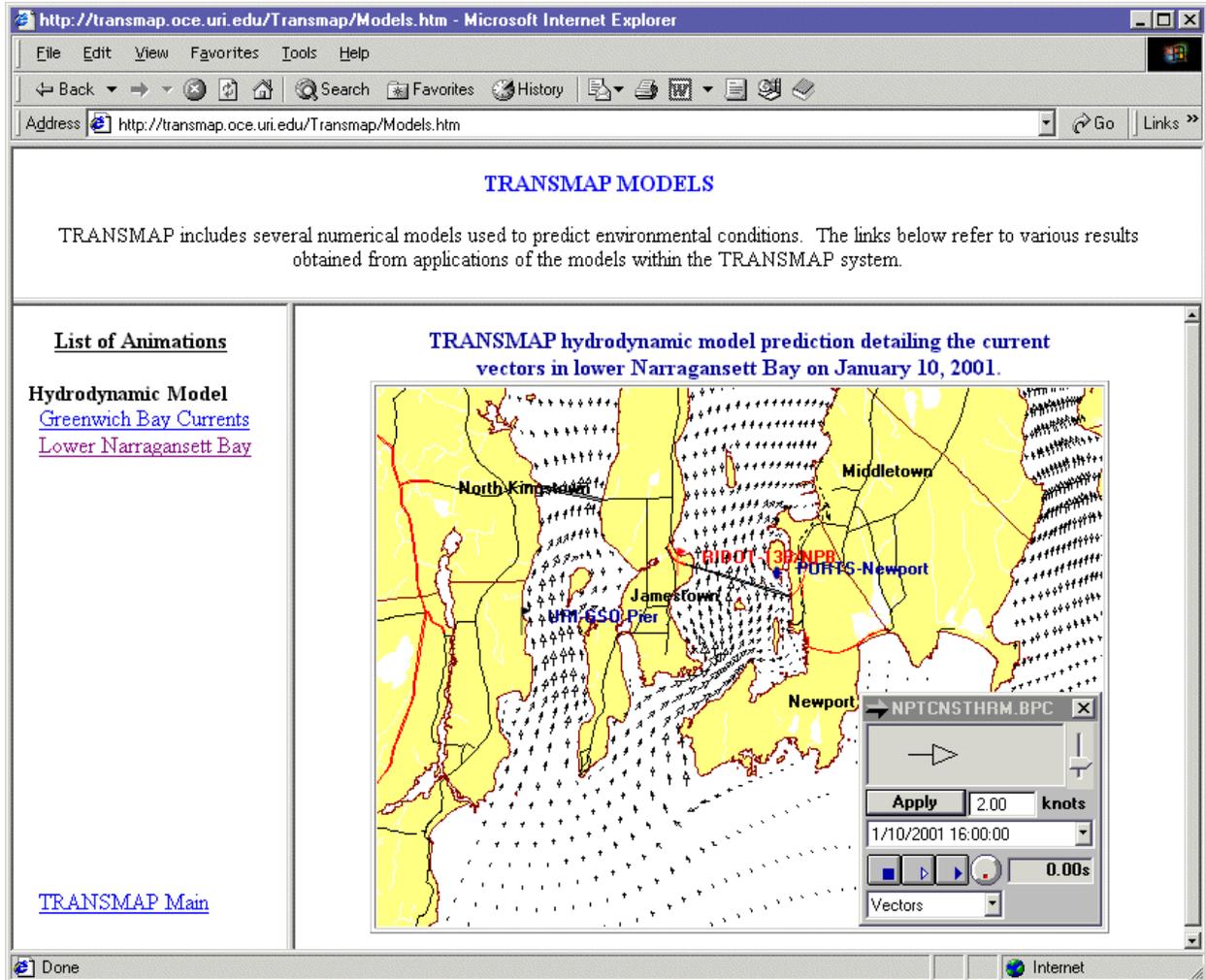


Figure 15. TRANSMAP/WEB animation of the tidal currents in lower Narragansett Bay. The plot shows hydrodynamic model predictions on January 10, 2001 at flood tide. Currents are observed entering the lower east and west passages of Narragansett Bay. The length of the current vectors indicates the current speed. The scale is provided in the animator control (insert lower right).

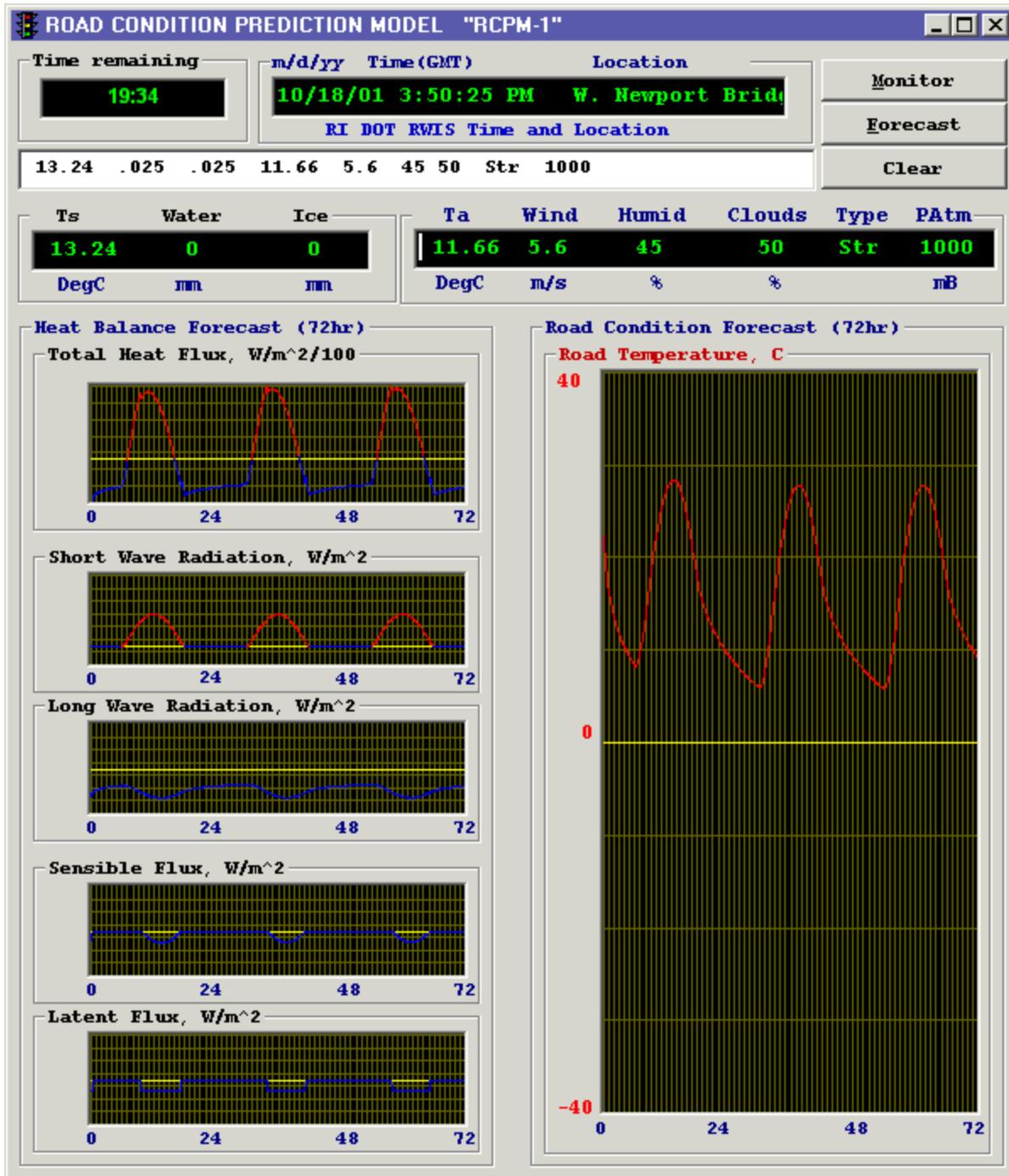


Figure 16. Forecast (72 hour) of the road surface heat flux and surface temperature by the Road Condition Prediction Model (RCPM) starting on October 18, 2001 for the West, Newport Bridge RI DOT RWIS site

Alpha Model Spill Location

Enter the geographic coordinates of the spill location in the fields below or click on the map to define the coordinates.

Click this form after entering Zoom or Interrogate mode to reset spill site entry by clicking.

Longitude (-180 to 180)

Latitude (-90 to 90)

- Emergency Response Mode -

Figure 17: **TRANSMAP** emergency response input form to specify the spill location for the ALOHA model.

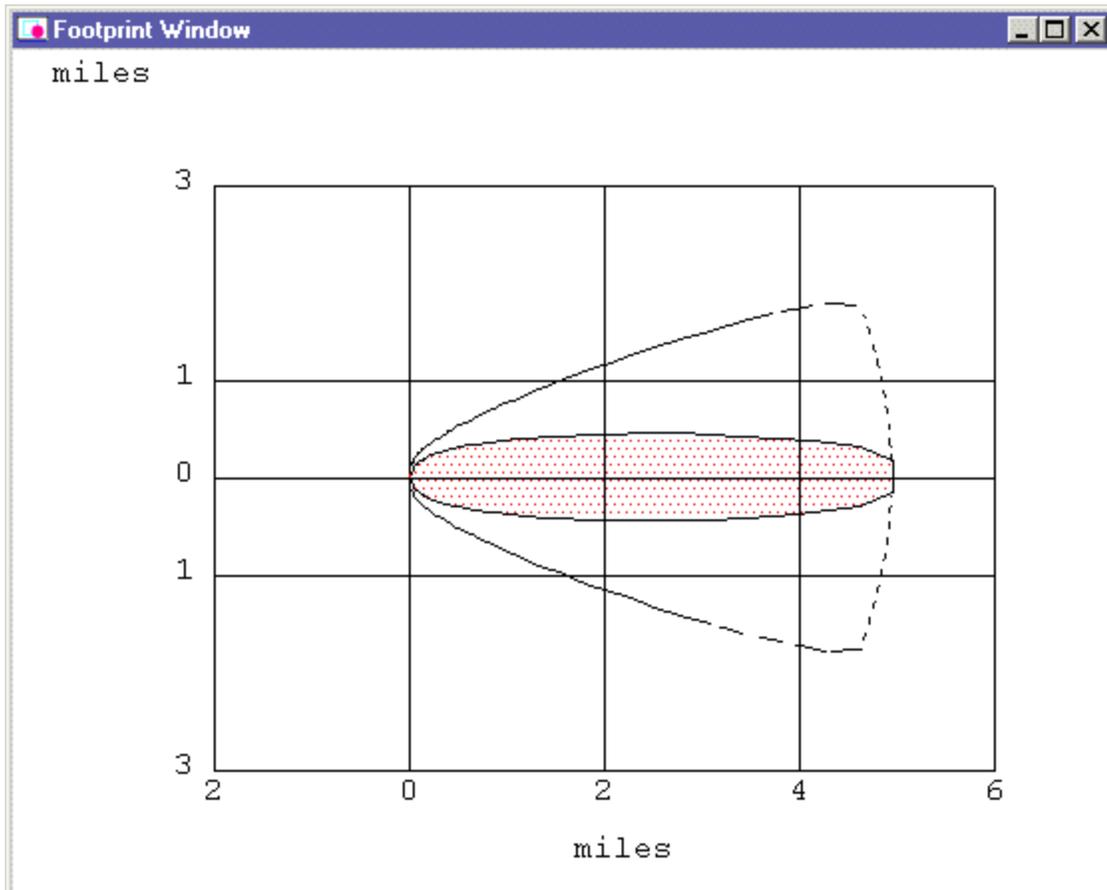


Figure 18. ALOHA model predicted footprint of the impact area from the atmospheric plume resulting from the chlorine spill on Rte 1 A in Narragansett, RI.

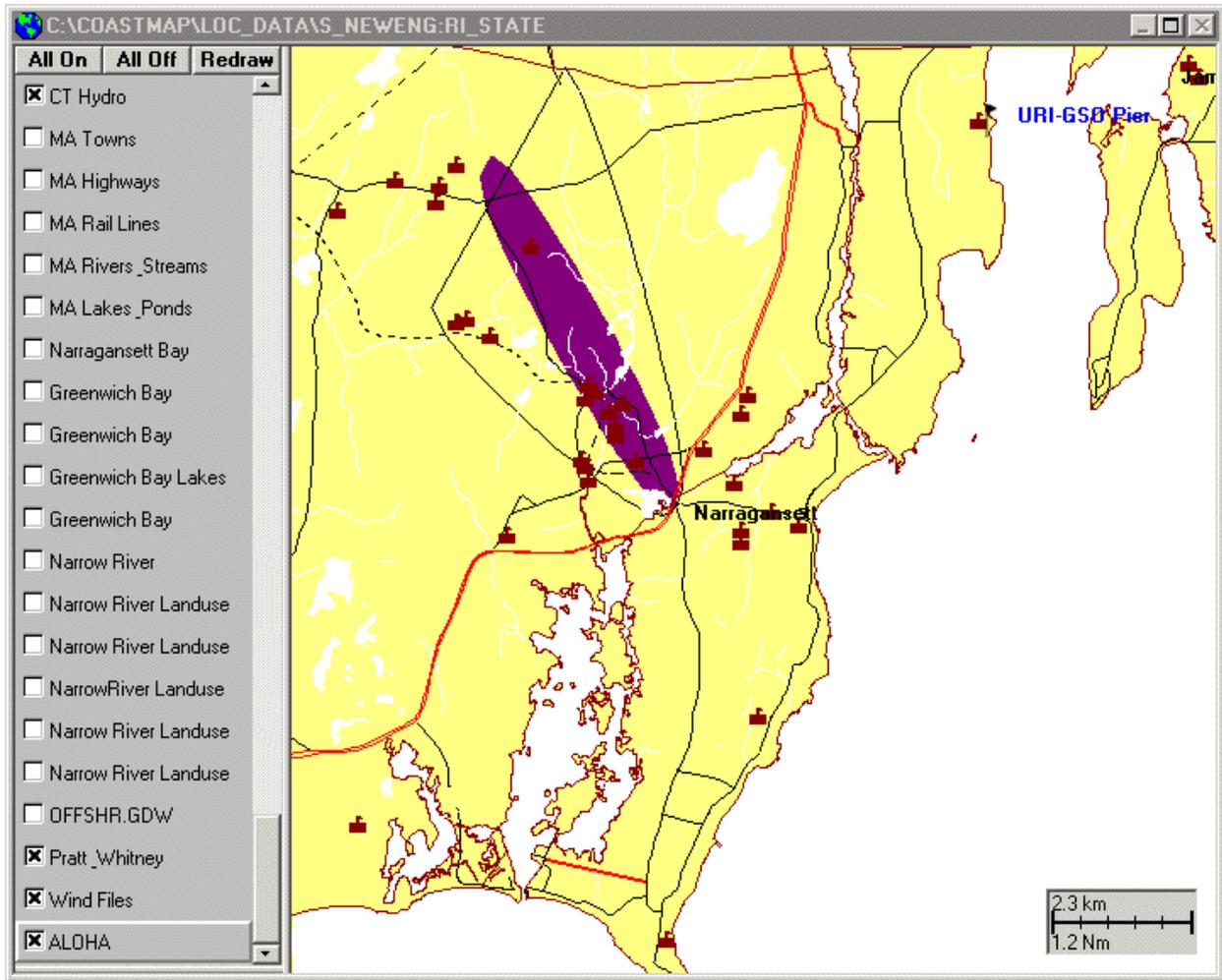


Figure 19. ALOHA model predicted footprint of the atmospheric plume resulting from the chlorine spill on Rte 1 A in Narragansett, RI overlaid on TRANSMAP's base map. The locations of the schools are shown as well.

| SCHOOLS_ | TYPE | LEVEL | GRADES | DISTRICT | NAME | ADDRESS |
|----------|-----------|------------|--------|---------------|--------------|--------------|
| 465 | PUBLIC | ELEMENTARY | 01-06 | SOUTH | WAKEFIELD | 101 HIGH |
| 466 | PUBLIC | ELEMENTARY | 01-06 | SOUTH | PEACE DALE | 109 KERSEY |
| 467 | PUBLIC | SR HIGH | 09-12 | SOUTH | SOUTH | 215 COLUMBIA |
| 468 | PRIVATE | PRESCHOOL | PK | NA | GINGERBREAD | 366 MAIN |
| 469 | PAROCHIAL | ELEMENTARY | PK-06 | CATHOLIC | MNSR | 5074 TOWER |
| 471 | PRIVATE | ELEMENTARY | PK-05 | NA | MEADOWBROOK | 35 NORTH |
| 472 | PRIVATE | PRESCHOOL | PK-KG | NA | CREATIVE | 30 SPRING |
| 473 | PRIVATE | PRESCHOOL | PK | NA | PEACE DALE | 261 COLUMBIA |
| 474 | PRIVATE | PRESCHOOL | PK-KG | NA | FIRST STEP | 25 W |
| 613 | PUBLIC | PRESCHOOL | PK-KG | SOUTH | HAZARD | 153 SCHOOL |
| 617 | PUBLIC | PRES-HIGH | PK-12 | COLLABORATIVE | SOUTHERN RI | 28 CASWELL |
| 624 | PRIVATE | HANDICAP | NA | NA | ACT/CHILDREN | 730 |

Figure 20. Summary list of the schools (name, location, grades, district and address) located within the impact zone shown in Figure 19.

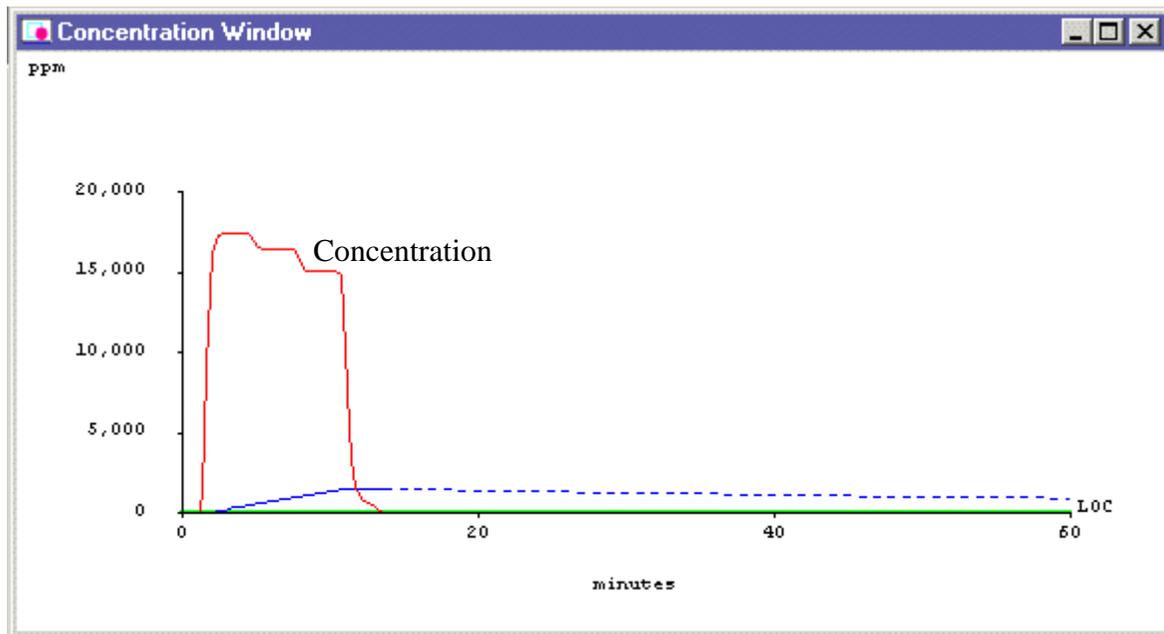


Figure 21. ALOHA predicted chlorine concentration (ppm) versus time at the Southern Rhode Island Regional Elementary School. The LOC is also provided.